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TEMPERATURE RELATIONS OF STONE FRUIT FUNGI

By CHARLES BROOKS and J. S. COOLEY, *Pathologists, Fruit Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture*

The two fungi that cause the heaviest market losses on peaches and other stone fruits are *Sclerotinia cinerea* (Bon.) Wor. and *Rhizopus nigricans* Ehr. The former is often referred to under its conidial name of Monilia and is the cause of brown rot, while the latter is the cause of black mold rot.

The present paper gives the results of investigations in regard to the temperature responses of these two fungi under various conditions of growth.

In all the experiments except that reported in figure 1 the spores were inoculated into the fruit from pure cultures. Except where otherwise stated the cultures were obtained from the host into which the inoculations were made. The fruit was warm when inoculated but after inoculation was placed in moist chambers and stored at once at the temperature indicated. Five or more peaches or prunes were used at each temperature in each test. The fruit was at the proper maturity for picking and shipping and was carefully selected for quality and soundness. In dividing the fruit into lots for distribution at the various temperatures uniformity was secured by selecting seven peaches or prunes (or as many as there were temperatures) that were similar in size, color and degree of maturity and distributing these one each in seven moist chambers and repeating the process till the desired amount of fruit was obtained.

Records were made of the diameters of the rots at intervals of one or two days, and the average of all the rots at a given temperature on a particular date was taken as a basis for plotting the curves in the accompanying figures. The equipment used in securing the various temperatures has been described in an earlier publication.[1]

SWEET CHERRIES

In 1919 a temperature experiment was made on Governor Wood cherries. These had been shipped by express from Wallingford, Conn., to Washington, D. C., and arrived somewhat bruised and with considerable brown rot. The specked and rotten cherries were discarded, but the slightly bruised ones were included in the experiment. The cherries were divided into five equal lots and distributed without inoculation at

[1] BROOKS, Charles, and COOLEY, J. S. TEMPERATURE RELATIONS OF APPLE-ROT FUNGI. *In* Jour. Agr. Research, v. 8, no. 4, p. 139–164, 25 fig., pl. 1–3. 1917.

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five different temperatures.[1] After 10 days' storage notes were taken and results obtained as shown in figure 1.

All of the cherries at 15° and 20° C. were partially or entirely rotten and nearly all of those at 10°. At 5° sixty-six per cent were affected, and at 0° thirty-four per cent. The results show the great inhibiting effect of low temperatures but perhaps give greater emphasis to the extreme difficulty of controlling Monilia rot at any temperature when the fruit has already received bad treatment and an opportunity has been given for the rot to pass through its initial stages while the fruit was warm.

PRUNES

But one temperature test has been made on prunes. The fruit was from Wenatchee, Wash., and was shipped from that point in a pony refrigerator August 31, 1920, arriving in Washington, D. C., in good condition 13 days later. Inoculations were made with Monilia and Rhizopus, and the fruit was distributed at once to the various temperatures. Figure 2 shows the development of the rots 5 days after inoculation.

PEACHES

A large number of temperature experiments have been made with Monilia and Rhizopus on peaches. The Carman, Belle, and Elberta peaches used in the 1918 experiments were purchased in the Washington market. The Belle and Elberta used in 1919 were from Rockville, Md., and the experiment was started the day after they were picked. The Carman and Belle peaches used in 1920 were from Vienna, Va., and were inoculated the day after they were picked. These peaches were slightly greener than those of the other experiments.

The curves of the various figures show very great uniformity. The Rhizopus cultures from peaches gave results similar to the cultures from cherries and strawberries, both in temperature response and in rapidity of rotting.

An interesting contrast is seen between the behavior of the fungi on peaches and on dextrose potato agar. A comparison of figures 3, 4, 5, and 6 with figure 7 shows that Monilia has grown just as freely at the higher temperatures and much earlier and more rapidly at the lower temperatures when grown on peaches than when on agar. At 10° C. rots usually became evident on the fruit within 3 days, while on the agar there was practically no growth at the end of 7 days. At 5° the rots were well started in 6 days, while the agar colony had scarcely made an equivalent growth at the end of 14 days. At 2½° the rots made a start in 8 to 12 days, but there was no evidence of growth on the agar at the end of 20 days. A comparison of figures 8, 10, 12, 14, 15, 16, and 17 with figures 9, 11, and 13 shows that the reverse condition holds with Rhizopus. This fungus made a more rapid growth and developed at lower temperatures on the culture media than it did on the fruit. On both food materials it had its most rapid growth at 30°. With the culture media the growth at 20° and 25° was but little slower than at 30°, but on the peaches the growth at 20° fell far behind that at 30°. At 15° and also at 10° the

[1] Temperature equivalents:

°C	°F.	°C	°F
20	68	5	41
15	59	0	32
10	50	..	..

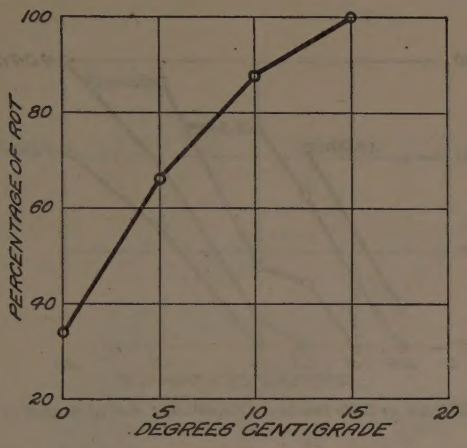

FIG. 1.—Natural infections of brown rot on Governor Wood cherries. The base line shows the temperature and the perpendicular the percentage of cherries affected with brown rot.

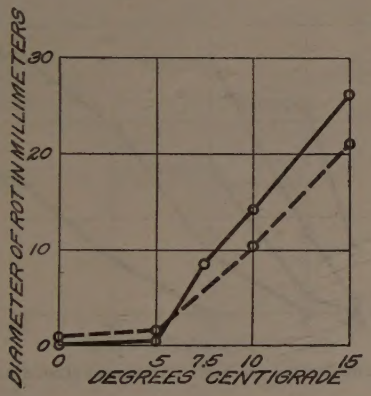

FIG. 2.—Monilia (solid line) and Rhizopus (broken line) on Italian prunes. Temperature is indicated on the base line and diameter of rot on the perpendicular.

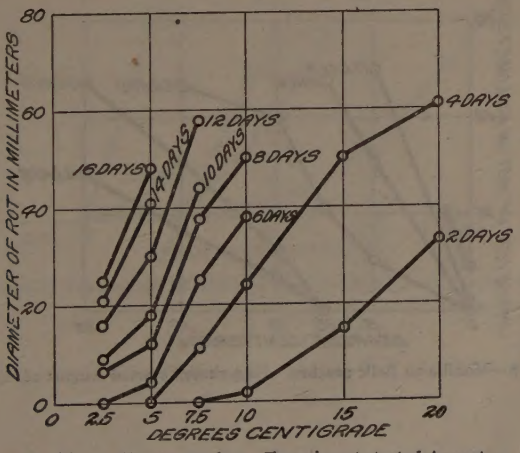

FIG. 3.—Monilia on Elberta peaches. Experiment started August 20, 1919.

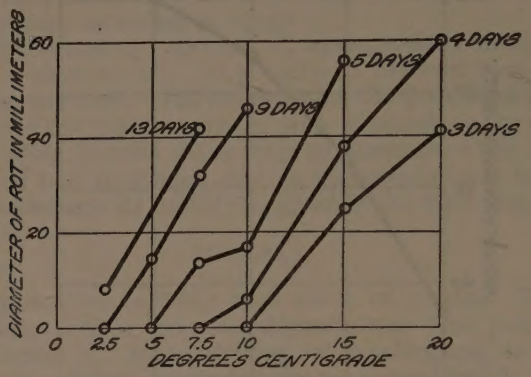

FIG. 4.—Monilia on Belle peaches. Experiment started August 27, 1919.

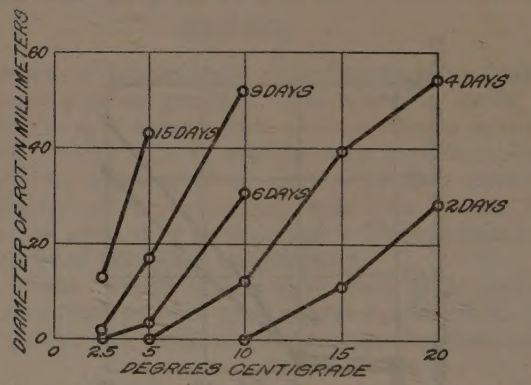

FIG. 5.—Monilia on Carman peaches. Experiment started August 5, 1920.

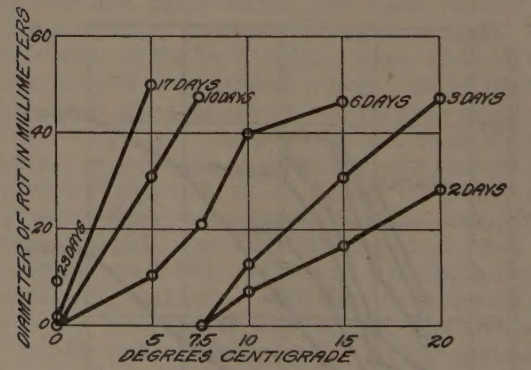

FIG. 6.—Monilia on Belle peaches. Experiment started August 28, 1920.

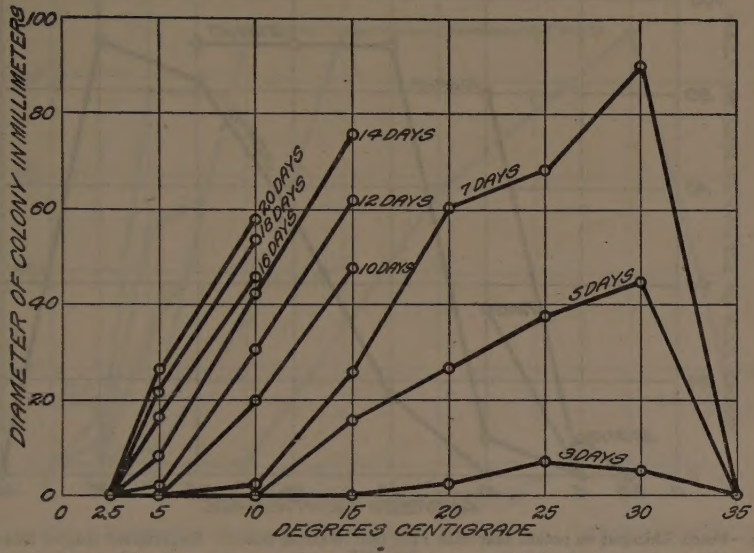

FIG. 7.—Peach Monilia on potato agar with 2 per cent dextrose added. In Petri plates. Experiment started November 22, 1918.

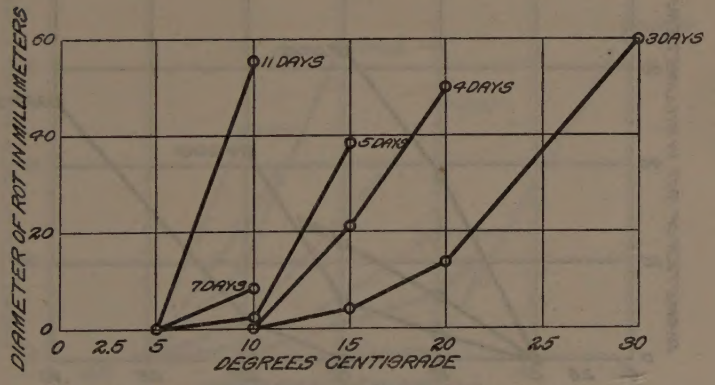

FIG. 8.—Peach Rhizopus on Elberta peaches. Experiment started August 23, 1918.

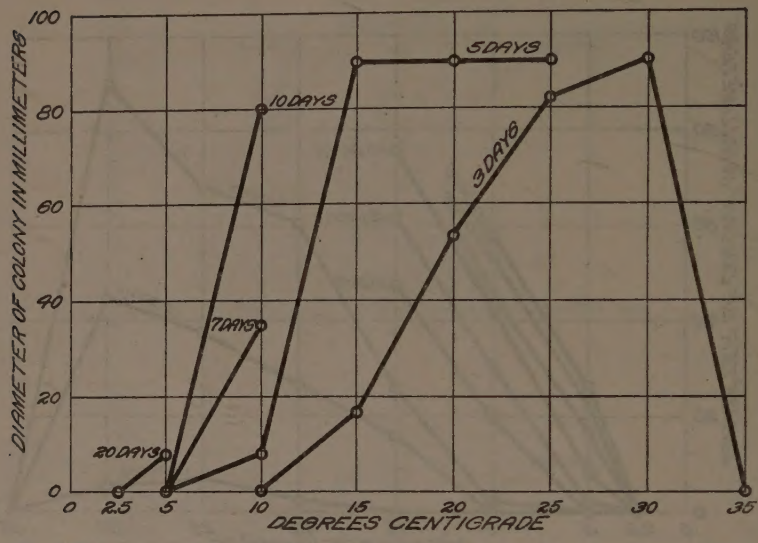

FIG. 9.—Peach Rhizopus on potato agar with 2 per cent dextrose added. Experiment started November 22, 1918.

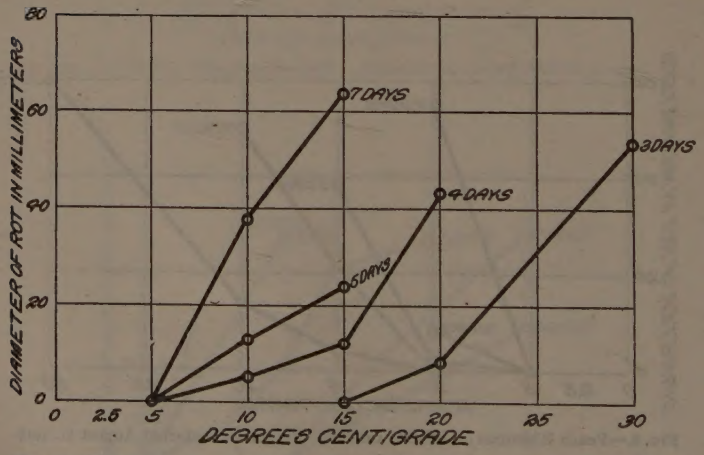

FIG. 10.—Cherry Rhizopus on Elberta peaches. Experiment started August 23, 1918.

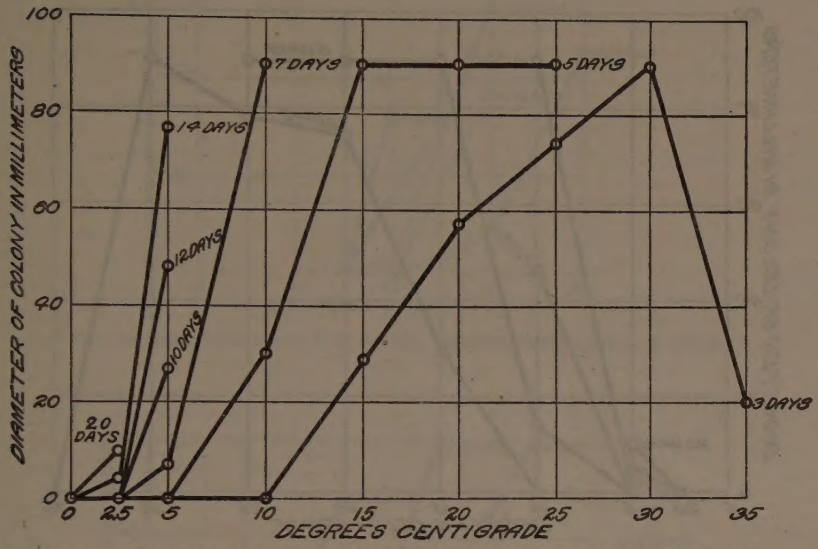

FIG. 11.—Cherry Rhizopus on potato agar with 2 per cent dextrose added. Experiment started November 22, 1918.

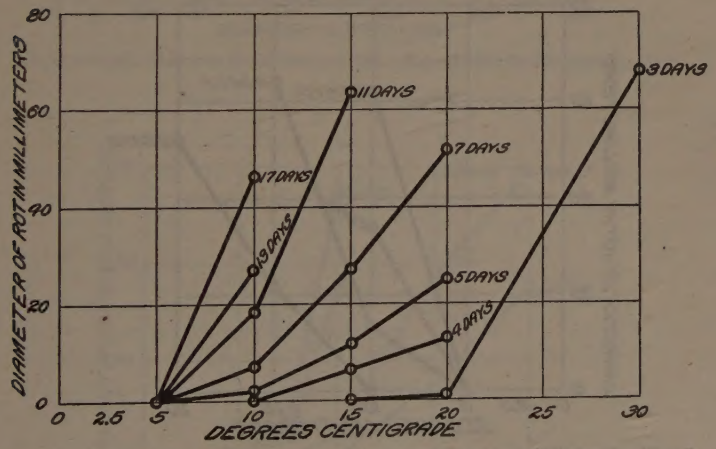

FIG. 12.—Strawberry Rhizopus on Elberta peaches. Experiment started August 23, 1918.

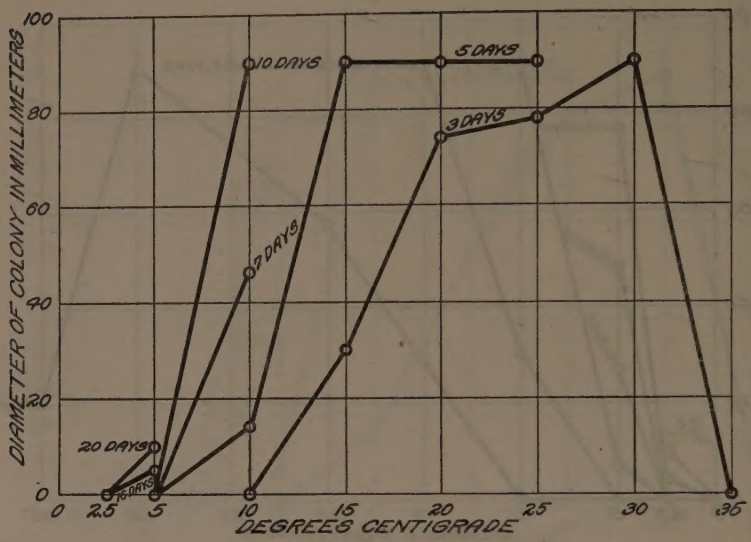

FIG. 13.—Strawberry Rhizopus on potato agar with 2 per cent dextrose added. Experiment started November 22, 1918.

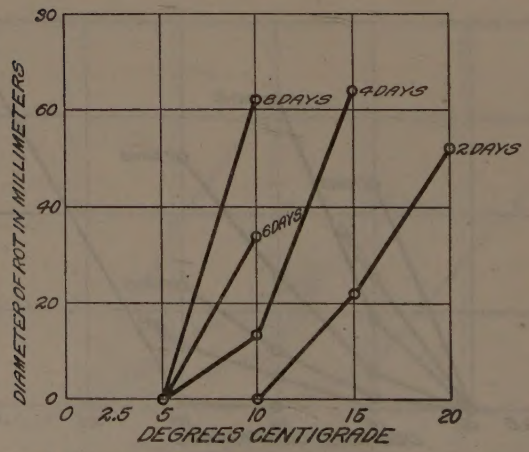

FIG. 14.—Peach Rhizopus on Carman peaches. Experiment started August 1, 1918.

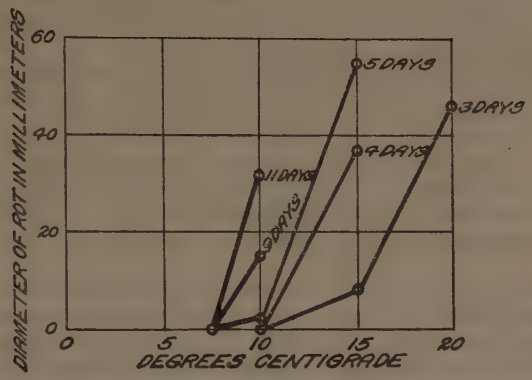

FIG. 15.—Peach Rhizopus on Belle peaches. Experiment started August 27 1919.

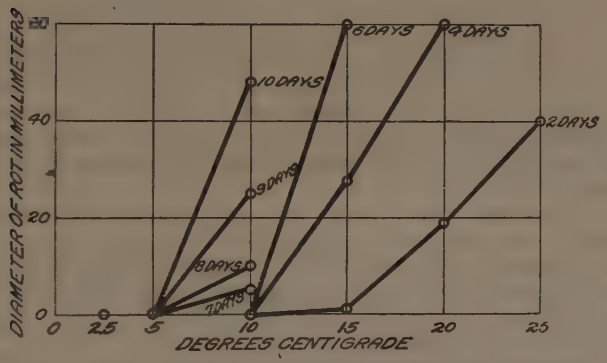

FIG. 16.—Peach Rhizopus on Carman peaches. Experiment started August 5, 1920.

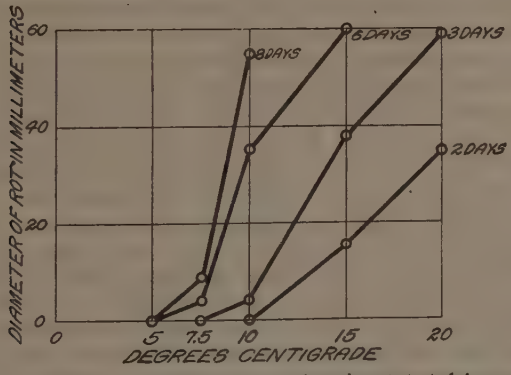

FIG. 17.—Peach Rhizopus on Belle peaches. Experiment started August 28, 1920.

growth started earlier and proceeded more rapidly on the agar than on the peaches. The fungus finally made a slow growth on the agar at 5°, but on peaches it made no growth at this temperature and with the exception of a few overripe peaches none at 7½°.

These contrasts in the behavior of the two fungi can probably be partly explained by the fact that Monilia is a parasite and adapted to growth on living material, while Rhizopus is a saprophyte and suited to growth on dead material, like the agar or inactive living material such as overripe fruit. It is interesting to note that with both fungi unfavorable food material and unfavorable temperatures work together in delaying growth, one unfavorable factor adding to the other in delaying or inhibiting activity.

A study of figures 3, 4, 5, 6, 18, and 20 gives a detailed idea of what can be expected of Monilia rot at any transportation or storage temperature. The results in the last two figures have been obtained by averaging those of the first four figures and therefore stand as a summary of the various experiments. With fruit that is infected with brown rot (Monilia) 3 days at 15° C. would result in heavy losses, 3 days at 10° would mean badly specked fruit that would go down rapidly at that temperature and that would be entirely destroyed by a day at a higher temperature. Brown rot can not get started in 3 days' time at 7½°, but by the end of the fourth day fruit at that temperature may be specked with rot. In 6 days the fruit at 5° may be spotted, in 9 to 12 days growth may be evident at 2½°, and at the end of 3 weeks rots may have started at 0°. Brown rot does not develop rapidly at the lower temperatures even when well started, yet its later growth is inhibited far less than its initial stages.

A study of figures 8, 10, 12, 14, 15, 16, 17, 19, and 21 shows that Rhizopus has more decided temperature limitations than those that have been pointed out for Monilia. The results in the last two figures have been obtained by averaging those of the first seven and therefore stand as a summary of the various Rhizopus experiments. At 15° and 20° C. the growth rate of Rhizopus rot is practically the same as that of Monilia rot, Rhizopus being a trifle more rapid at 20° and Monilia just a little more rapid at 15°. At 10° Monilia rot develops more than twice as fast as Rhizopus rot, and at 7½° Rhizopus is practically eliminated.

Whether Rhizopus could make any start whatever at 7½° C. seemed to be determined mainly by the maturity of the fruit. The curves of figure 15 show that Rhizopus had not made a start at 7½° in 11 days. The peaches at that temperature were still free from rot at the end of 14 days, were removed to a warm room at that time, and were entirely rotted with Rhizopus 2 days later. The results show that the fungus was held completely in check at 7½° but was alive and ready for rapid development when given a more favorable temperature. With the experiments reported in figure 17, Rhizopus had produced evident rotting at 7½° in 6 days. At that time only the ripest peaches were affected, but at the end of 12 days rots began to develop on the greener peaches. When once started at this temperature Rhizopus rot made a fairly rapid growth. The results as a whole show that with the usual number of days in transit for most peach shipments Rhizopus can produce little or no damage at 10° and none at 7½°.

Figures 3 to 21, inclusive, show the development of the rots when the fruit is stored at the given temperatures immediately after inoculation. Figures 22, 23, and 24 show the effect of 1 day's delay at a higher tem-

perature than that at which the fruit was finally held. A study of the figures brings out the facts that with Monilia 1 day at 25° C. followed by 1 day at 10° results in as large spots as 5 days at 10°; 1 day at 20° followed by 1 at 10° results in as large spots as 4 days at 10°; 1 day at 25° followed by 1 at 7½°, in as large spots as 6 days at 7½°; 1 day at

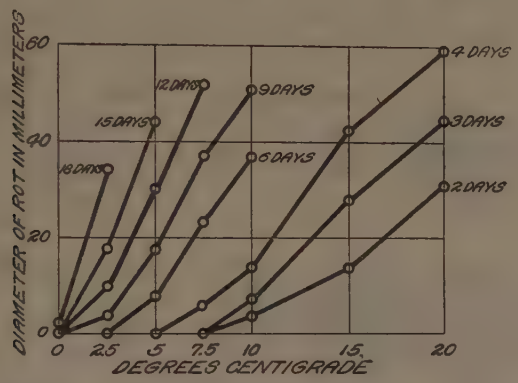

FIG. 18.—Monilia on peaches. A summary of the experiments on brown rot obtained by averaging the percentages of figures 3, 4, 5, and 6.

25° followed by 1 day at 5°, in as large spots as 10 days at 5°; 1 day at 25° followed by 1 day at 2½°, in as large spots as 12 days at 2½°. It will also be seen that with Rhizopus 1 day at 25° followed by 1 day at 10°, or 1 day at 15° followed by 4 at 10°, results in larger spots than 7 days continuously at 10°.

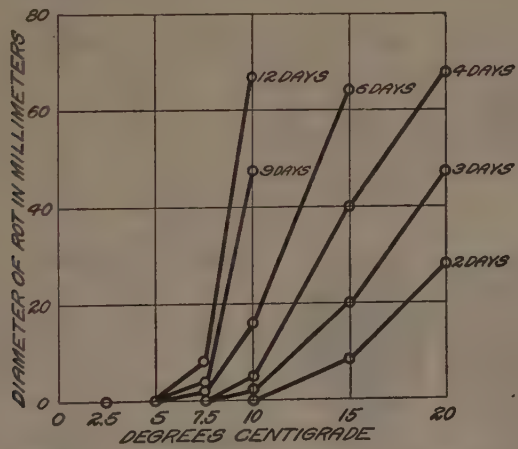

FIG. 19.—Rhizopus on peaches. A summary of the experiments on Rhizopus rot obtained by averaging the percentages of figures 8, 10, 12, 14, 15, 16, and 17.

Peaches inoculated with Monilia and promptly cooled to 2½°, 5°, 7½°, or even 10° C. have had but little or no rot at the end of 3 or 4 days, but similarly inoculated peaches delayed at 25° for 1 day before storing at these lower temperatures have developed so much rot by the end of the fourth day after inoculation that they were commercially worthless. Peaches inoculated with Rhizopus and promptly cooled to 10° have been

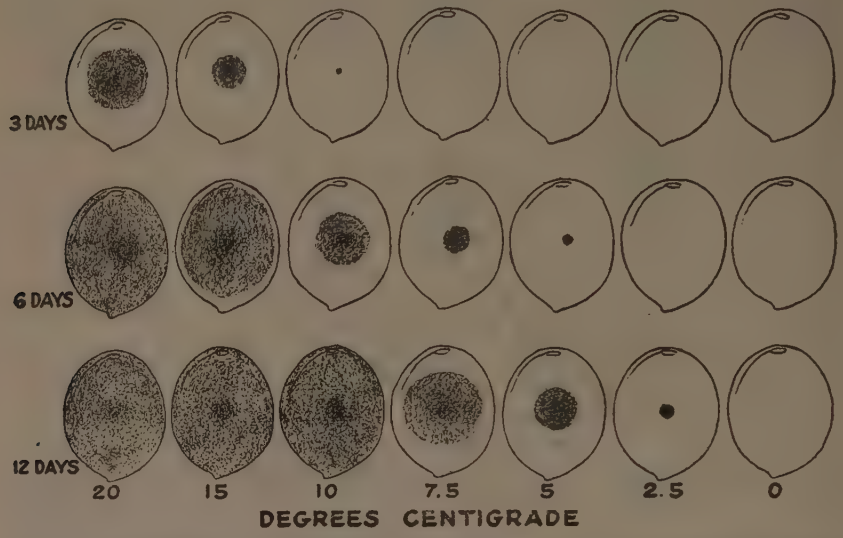

FIG. 20.—Monilia on peaches. The drawings represent the average of the results from the various experiments. The shaded portions indicate the extent of the decay. The upper series shows the size of the rots at the various temperatures after 3 days, the second series the size after 6 days, and the third the size after 12 days.

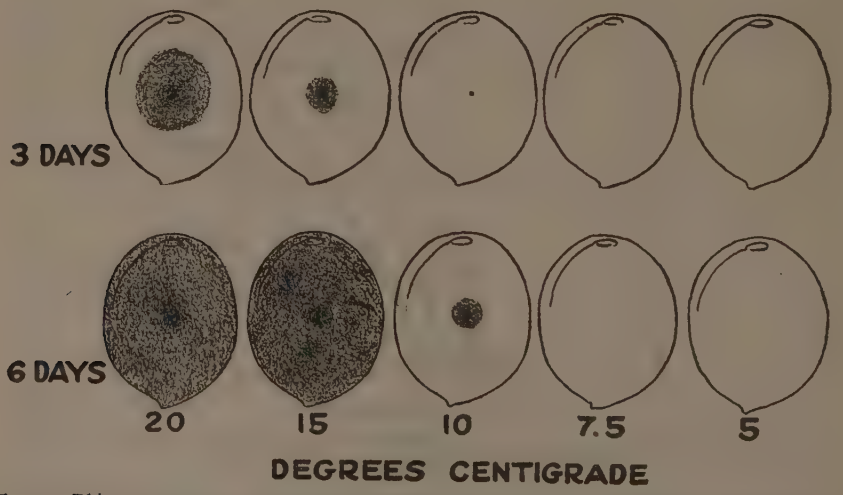

FIG. 21.—Rhizopus on peaches. The drawings represent the average of the results from the various experiments. The shaded portions indicate the extent of the decay. The upper series shows the size of the rots at the various temperatures after three days and the second series the size after six days.

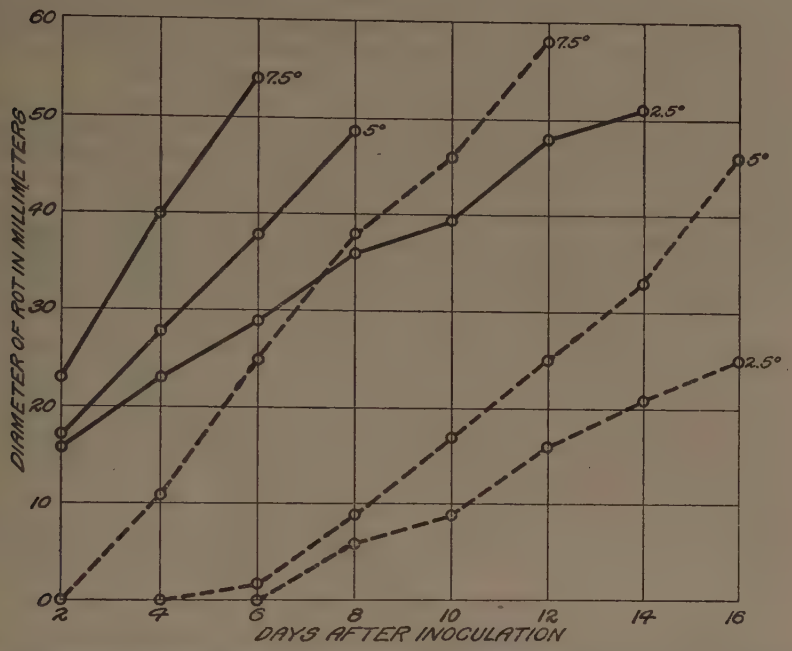

FIG. 22.—Effect on Monilia rot of one day's delay at 25° C. The base line shows the number of days after inoculation and the perpendicular the diameter of the rots. The curves show the rate of development of the rots at the temperatures indicated at the end of the lines. The dotted lines give the results on the fruit placed at once at the given temperatures and the solid lines the results on similar fruit delayed one day at 25° before placing at these temperatures. Elberta peaches, August 20, 1919.

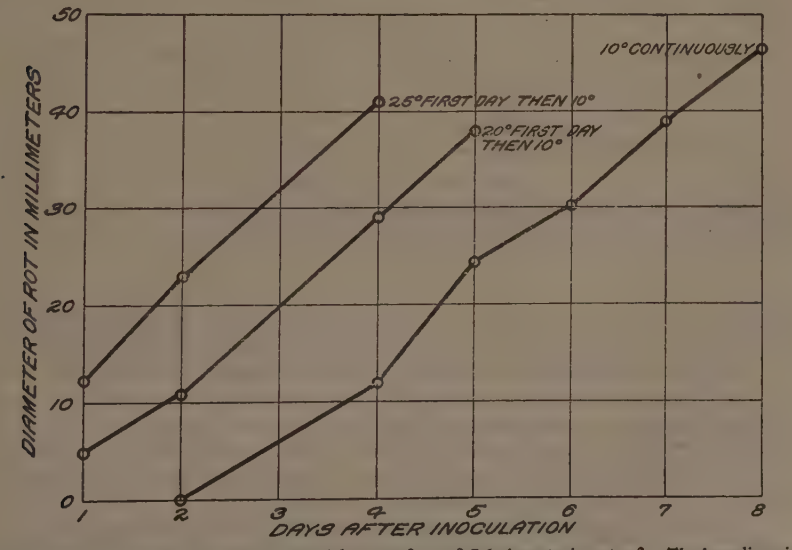

FIG. 23.—Effects on Monilia rot of one day's delay at 25° or 20° C. before storing at 10°. The base line gives the number of days after inoculation and the perpendicular the diameter of the rots. The curves show the development of the rots under the particular storage treatment. Experiment on Carman peaches, August 5, 1920.

entirely free from rot at the end of 6 days, while similarly inoculated peaches delayed for 1 day at 25° before storing at 10° have been almost entirely rotten at the end or 6 days, and those held at 15° before storing at 10° have been considerably damaged by the end of 6 days.

The results show the great value of low temperatures in controlling peach rots and the extreme importance of securing these temperatures promptly. It is evident that in unfavorable weather success with long-distance shipments requires not only a low car temperature upon arrival at destination but a low temperature from the time the peaches are packed and as much coolness as possible from the time they are picked. It is not an unusual thing for peaches to remain at the prevailing seasonal temperature for a day or more before being loaded into

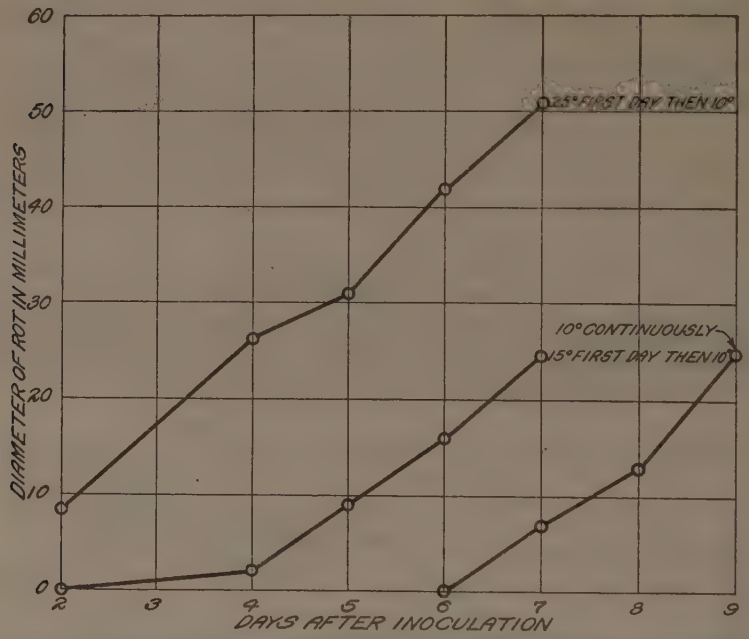

FIG. 24.—Effects on Rhizopus rot of one day's delay at 25° or 15° C. before storing at 10°. The base line gives the number of days after inoculation and the perpendicular the diameter of the rots. The curves show the development of the rots under the particular storage treatment.

the car, and with most makes of refrigerator cars and the usual methods of icing it is likely to be one or two more days before a really protecting temperature is secured. The fruit in the top layers is often still above 10° C. after several days in transit. Prompt loading, better refrigerator cars and heavier icing, particularly during the first part of a trip, would contribute greatly to lengthening the life of stone fruits; but the experiments that have been reported show that there would still be a gap that would sometimes result in heavy losses of fruit and that could only be filled by some method of precooling.

One of the unfortunate things in regard to delayed cooling is that its harmful effects may not be immediately evident. Peaches may appear practically sound after a delay before loading and cooling and yet that delay may have allowed the rots to make a start that will require

that the temperature be held several degrees lower or that the destination be selected several days nearer in order to insure the delivery of sound fruit.

SUMMARY

(1) A temperature of 10° C. (50° F.) has held Monilia in check for one or two days and Rhizopus in check for three days. A temperature of 7½° C. (45½° F.) has held Monilia in check for three days and Rizopus in check for six or more days. A temperature of 5° C. (41° F.) has held Monilia entirely in check for four days, and 2½° C. (36½° F.) has held it in check for six days.

(2) Low temperatures have resulted in relatively less inhibition of growth with Monilia when grown on peaches than when grown on potato-dextrose agar, and a relatively greater inhibition with Rhizopus when grown on peaches than when grown on potato-dextrose agar. Both fungi have grown at lower temperatures on ripe fruit than on green fruit.

(3) Peaches stored at 10° C. (50° F.) immediately after inoculation have been three to five days slower in developing rot than those delayed one day at 25° C. (77° F.) before storing at 10° C. (50° F.). Peaches stored immediately at 7½° C. (45½° F.) have been five days slower in developing brown rot than those delayed one day at 25° C. (77° F. before storing at 7½° C. (45½° F.).